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Electrical conductivity of the stratosphere over Hyderabad, India: Results from Balloon borne measurements

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The stratospheric conductivity is an important parameter of the global electric circuit. In this paper, the stratospheric conductivity measurements are presented, which were made using high altitude balloon flights from Hyderabad (geographic 17.5°N, 78.5°E; magnetic lat 8.5°N), India as a part of the IMAP (1982-1994) program of India. The vertical profiles of ion conductivity were measured from Hyderabad during periods with different solar activity levels and during different seasons using different techniques. It was observed that conductivity values in stratosphere are larger in high solar activity period as compared to low solar activity period. This is similar in nature to the observations from mid-latitudes. The observed positive correlation with solar activity is discussed in terms of composition changes due to the change in intensity of the UV (200-300 nm) radiation with solar activity. It was found that the dissociation of heavy cluster ions to lighter ions, as conjectured by Gupta [Solar cycle variation of stratospheric conductivity over low latitude, *Adv Space Res* (*UK*), 26 (2000.) pp 1225–1229] is the main reason for the observed positive correlation of stratospheric conductivity with solar activity. No significant seasonal effect was noticed. In addition, conductivity profile obtained from Hyderabad is compared to that obtained from Cachoeira Paulista, Brazil.

Keywords: Stratosphere, Electrical conductivity, Photo-dissociation, Ion conductivity, Solar activity

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1 Introduction

Electrical conductivity, which is proportional to the product of the ion concentration and the ion mobility increases exponentially with altitude in the troposphere and stratosphere. Variations in conductivity may be caused by factors that can change either or both of these quantities. For instance, the ion concentration can change as a result of the variations in the cosmic ray flux, which is the source of ionization in the stratosphere and troposphere[2,3]. The stratospheric conductivity is an important parameter of the global electric circuit[4-6]. The conductivity in the stratospheric region is measured using Balloon-borne experiments. In the past, there were several such campaign mode observations, which provided several new insights to this topic. For example, measurements of the atmospheric conductivity from nine high-altitude balloon flights obtained between the altitudes of 10 and 30 km at three locations widely separated in latitude provided the conductivity variations on local and global scales[7]. The observations were made during 1973-1981 period. The vector electric field and polar conductivities were measured by balloon-borne payloads launched from Wallops Island, Virginia during the summers of 1987 and 1988[8]. Similarly, during the polar patrol balloon (PPB) campaigns, direct electric field and conductivity measurements were made from Antarctica[9,10]. Balloon-borne measurements of the conductivity from near ground level to 35 km were studied in conjunction with measurements of the ionization rate and the positive ion density and three parameters were used to calculate the average positive ion mobility profile and the effective recombination coefficient profile, using data from Laramie, from the flights during 1978-1979[11]. All these measurements pertain to the mid and polar latitudes.

One of the very important programs to study the variability of the middle atmospheric electrodynamics was the Indian Middle Atmospheric Program (IMAP), an important element of which was the Indian Middle Atmospheric Conductivity Campaign[1,12,13]. The two phases of this national program spanned from 1982 to1994, during which the vertical profiles of conductivity were measured using different techniques from a low-latitude station Hyderabad (geographic 17.5°N, 78.5°E; magnetic lat 8.5°N). The uniqueness of this database is that it covers both the high and low solar activity periods as well as different seasons. Using the data from four flights, it was shown that conductivity values in stratosphere are larger in high solar activity period as compared to low solar activity period. It was suggested that during high solar activity period, the heavy cluster ions dissociate into lighter ions giving rise to the enhanced conductivity over this region[1]. The main objective of this paper is to further show the solar activity dependence of stratospheric conductivity. In the present paper, the data from the four flights already published by Gupta[1] is used and added from two more flights corresponding to low (daily mean sunspot number R_z = 26) and high (R_z =167) solar activity periods to show that the results are consistent. Further, by extracting the altitude variation of the difference in conductivity during solar maximum and minimum, it is qualitatively proved that the composition changes due to the changes in the UV radiation intensity with solar activity[14,15] is a principal cause for the positive correlation of stratospheric conductivity with solar activity. It must be mentioned here that data obtained from same technique were compared for low and high solar activity periods. For example, the Langmuir probe (LP) data obtained on 6 December 1995 is compared with that on 22 April 1989, which was also obtained using LP. This was done to take care of the difference in values that may arise due to the difference in the measurement technique. Apart from this, conductivity profile obtained from Hyderabad on 5 January 1994 is compared to that obtained from Cachoeira Paulista, Brazil (geographic 22°44′S 44°56′W; geomagnetic 11°57′S, 22°32′E) for 26 January 1994 to show the longitudinal differences in conductivity.

2 Experimental technique

The list of observations along with the corresponding sunspot number is given in Table 1. The balloon flights on 8 April 1987 and 6 December 1989 used a ‘long wire’ probe and those on 17 October 1989 and 5 January 1994 used a ‘spherical probe’. Both these measurements were based on relaxation time measurements. In this technique, one or more probes are driven to a potential different from the ground potential of the payload for a short period of time; the potential difference is then released and the probe potential is allowed to decay exponentially to a steady state value[16]. The sensor is a hollow spherical copper sphere of 20 cm diameter, coated with aquadag and mounted on a boom of one meter length on balloon gondola. A voltage pulse of ±5 V is applied for a duration of 1 sec with an interval of 50 sec. The decay time constant is measured and the conductivity is calculated using the following equation[17]:

$$= - \qquad \ldots(1)$$

where, , is the permittivity of the medium[1,18].

The balloon flights on 6 December 1985 and 22 April 1989 used Langmuir Probe (LP) for measuring the vertical profiles of polar conductivity. The payload consisted of an electrostatic sensor, which is hemi-spherical (10 cm diameter) in shape and made of stainless steel. In this technique, a suitable potential is applied to the sensor with reference to the reference electrode and the resulting current is measured. Depending on the potential of the probe, it would collect either positive or negative ions. The conductivities are derived from the resulting I-V characteristics:

$$\propto \frac{dI}{dV_P} \qquad \ldots(2)$$

where, V_P, is the probe voltage.

3 Results and Discussion

Figure 1(a-c) shows the vertical profiles of negative ion conductivity measured over Hyderabad during the IMAP campaigns. The daily sunspot number data are taken from NSSDC (http://omniweb.gsfc.nasa.gov/form/dx1.html). Figure 1(a) compares the profiles of negative ion conductivity on 8 April 1987 (low solar activity, R_z=64) with that on 6 December 1989 (high solar activity, R_z=187). As mentioned earlier, both are ‘long wire’ probe measurements based on relaxation time. It can be seen that the conductivity increases exponentially with altitude. It can also be seen that the conductivity is high at all altitudes during high solar

Table 1 — List of observations

Date of observation	Sunspot number
6 December 1985	26
8 April 1987	64
22 April 1989	167
17 October 1989	206
6 December 1989	184
5 January 1994	104

activity day compared to low solar activity day[1], and the difference increases with altitude. Figure 1(b) compares the vertical profiles of negative ion conductivity on 5 January 1994 (low solar activity, R_z=107) with that on 17 October 1989 (high solar activity, R_z=206). These are also 'relaxation time probe' measurements but with a spherical probe. Here also, the positive correlation with solar activity is evident. Figure 1(c) compares the vertical profiles of negative ion conductivity on 6 December 1985 (solar minimum, R_z =26) with that on 22 April 1989 (solar maximum, R_z=167). These are LP measurements, and hence one cannot compare the absolute value of conductivity with the previous ones. However, both the measurements shown in Fig. 1(c) can be compared, since both are LP measurements. It can be seen that the conductivity is high at all altitudes during high solar activity day compared to solar minimum and the difference increases with altitude.

Gupta[1] suggested that the dissociation of the heavy cluster ions into lighter ions plays a crucial role in enhancing the conductivity during solar maximum period. To substantiate this further, the mean profile of difference in negative ion conductivity with the standard deviations is taken and calculated at each km [Fig. (2)]. It can be seen that the difference increases exponentially with altitude with a scale height (distance over which a quantity decreases by a factor of *e*) of ~8 km. This value matches with the scale height of the UV radiation (decreases as one goes lower in altitude). The available flux UV radiation for dissociation of cluster ions will be more at higher altitudes and hence, one can expect the difference in conductivity also to be more at higher altitudes. In other words, the scale height of the difference in conductivity (between high and low solar activity) and scale height of the change in UV radiation with altitude are identical in nature, and this further adduce the role of dissociation of cluster ions by UV radiation in increasing the conductivity. It may be noted here that the percentage changes in UV radiation are not being related with that of stratospheric conductivity because the global or local variations in the ion mobility can occur due to changes in the ion recombination rate, and hence, any relationship between ion mobility change and percentage change in UV radiation would not be linear. However, if the cause of the positive correlation of conductivity with solar activity lies in the variability of UV flux, then both would show similar scale heights as it is observed. Hence, one can qualitatively conclude that dissociation of the cluster ions and the resultant enhancement in mobility causes the enhancement in the conductivity during solar maximum period.

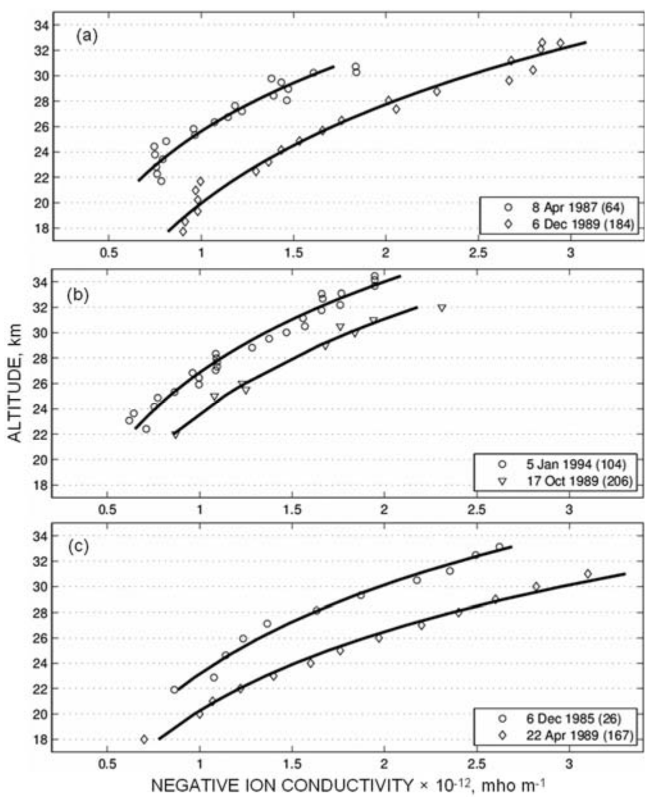

Fig. 1 — Conductivity profiles observed from Hyderabad, India: Comparison of measurements using: (a) long wire probe; (b) spherical probe; and (c) LP for different solar activity levels [daily sunspot numbers corresponding to the days are given in legend; thick solid lines are exponential fits]

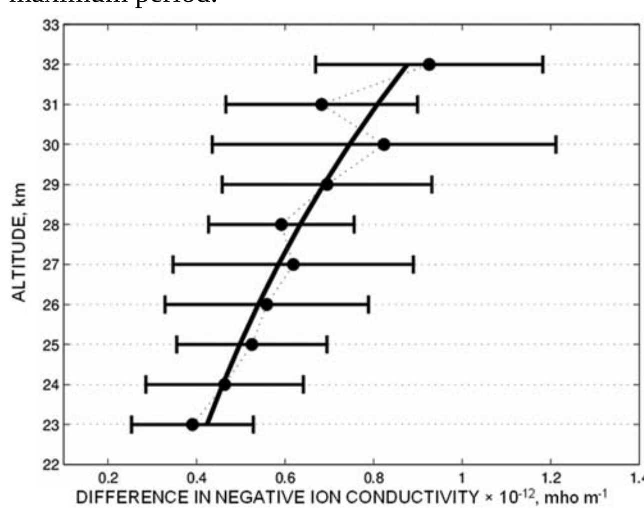

Fig. 2 — Profile of the mean difference in negative ion conductivity (between high and low solar activity days) with the standard deviations [thick solid line shows an exponential fit]

Another important aspect which needs to be considered while addressing the long term changes in the stratospheric conductivity is the variation in the ionization due to galactic cosmic rays. Cosmic ray particles with energy greater than 1 Gev can reach over equator. Figure 3 shows the yearly averaged maxima of ion production due to galactic cosmic ray in the stratosphere corresponding to three magnetic latitudes (75°, 60°, and 45°). This is reproduced from Krivolutsky[19]. It can be seen that the galactic cosmic ray intensity shows substantial solar cycle dependence only for 75° and 60° magnetic latitudes with maximum intensity on solar minimum period and minimum intensity during solar maximum period. Such clear solar activity dependence is not seen at 45° magnetic latitude. This indicates that the ion production in the stratosphere does not vary significantly with solar activity. The stratospheric conductivity is determined by the ionization produced by the galactic cosmic rays and the ion mobility. At high latitudes, the cosmic ray flux has an inverse correlation with solar activity, whereas at mid-latitudes, this inverse correlation is not seen. However, it is observed that stratospheric conductivity has a positive correlation with solar activity. In fact, the positive correlation holds good at mid-latitudes as well. For instance, if one compares the conductivity profiles from Palestine (32°N geographic)[20] for 1 September 1976 (low solar activity R_z=17) with that of 6 July 1999 (higher solar activity R_z=141), one can see that the conductivity is high in high solar activity period. These observations suggest that one cannot attribute the observation that the stratospheric conductivity has positive correlation with solar activity to any changes in the cosmic ray fluxes. It must be mentioned here that similar trend can be seen in the conductivity variations over the South American sector as well. For instance, if one compares the conductivity value at 26 km reported by Pinto *et al.*[21] corresponding to high solar activity (April 1980, Rz=164) to that reported by Saba *et al.*[22], for low solar activity period (January 1994, Rz=67), a similar trend can be seen.

Figure 4 compares the conductivity profile obtained from Hyderabad on 5 January 1994 and that obtained from Cachoeira Paulista, Brazil (geographic 22°44′S, 44°56′W; geomagnetic 11°57′S, 22°32′E) for 26 January 1994. The measurement over Cachoeira Paulista, Brazil is reproduced from Saba *et al.*[22]. These are also made using a relaxation time probe[22]. Such a comparison of observations from two separate locations during same month and year was not done previously because the balloon-borne observations comprise only a very small database around the globe and near simultaneous measurements from two such locations were not available. An important point to be noted here is that the magnetic field strength is different at these two stations. It must also be mentioned here that the profile reported by Saba *et al.*[22] is obtained before the thunderstorm event when the balloon was ascending. The thunderstorm started after the balloon reached the float altitude[22]. Though the comparison is made using only one flight each for a location, considering the fact that very few observations are available over the world, this observation is considered very important. From this single observation, it appears that since

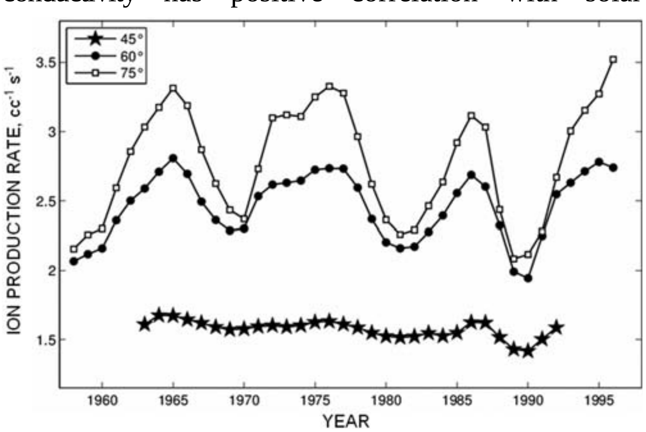

Fig. 3 — Yearly averaged maxima of ion production rate due to galactic cosmic rays in the stratosphere corresponding to three magnetic latitudes [*Source*: Krivolutsky, Large scale / long term ozone response in connection to comsic influence, in ***Long term changes and trends in the atmosphere*** Vol I, 2000]

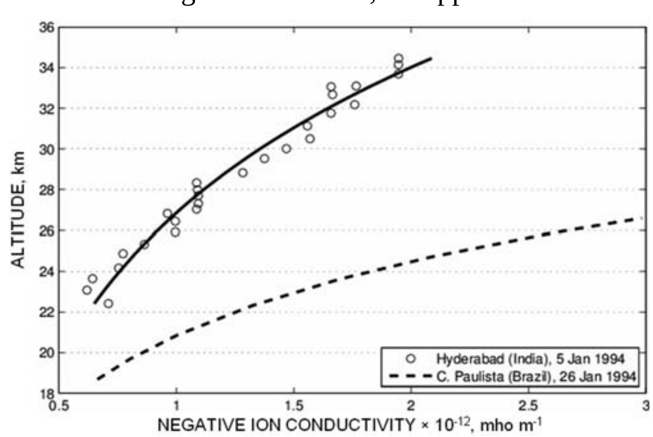

Fig. 4 — Conductivity profile obtained from Hyderabad on 5 January 1994 and from Cachoeira Paulista, Brazil for January 26 1994 [*Source*: Saba ***et al.***, Stratospheric conductivity measurements in Brazil, *J Geophys Res* (USA), 104 (D22) (1999) pp 27203-27208, doi: 10.1029/1999JD900221]

magnetic field value at Brazil is lower than over Indian zone, the conductivity is also higher over Brazil compared to India. However, more coordinated observations are needed to further confirm the differences.

4 Conclusion

The stratospheric conductivity measurements made using high altitude balloon flights from Hyderabad, India as a part of the IMPAP (1982-1994) program of India show that conductivity values in stratosphere are larger in high solar activity period compared to low solar activity period. This observation is similar in nature to that observed at mid-latitudes. The mean differences in negative ion conductivity increases exponentially with altitude and has a scale height of ~8 km. This value matches with the scale height of the UV radiation. This confirms the role of dissociation of cluster ions by UV radiation in increasing the conductivity. Another important aspect revealed by the present investigation is that the conductivity over Cachoeira Paulista, Brazil is significantly higher, than that observed over Hyderabad.

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